LESSON 5

TOPIC 1

Slope Stability

SLOPE STABILITY

Lesson 5 - Topic 1

Slide 5-1-1

SLOPE STABILITY

1. Compute Resisting & Driving Forces
2. Explain Effects of Water Pressure on Frictional Resistance

ACTIVITIES: Circular Arc Analysis
Sliding Block Analysis

Slide 5-1-2

Embankments: Major Design Considerations

- ***Stability***
- ***Settlement***
- ***Effects on the Structure***

Slide 5-1-3

Embankment Stability Problem Soils

- ***Low Strength Clays***
- ***Low Strength Silts***
- ***Peats***
- ***Organic Silts and Organic Clays***
- ***Thin, Weak Seams (Clay, Silt, Sand)***

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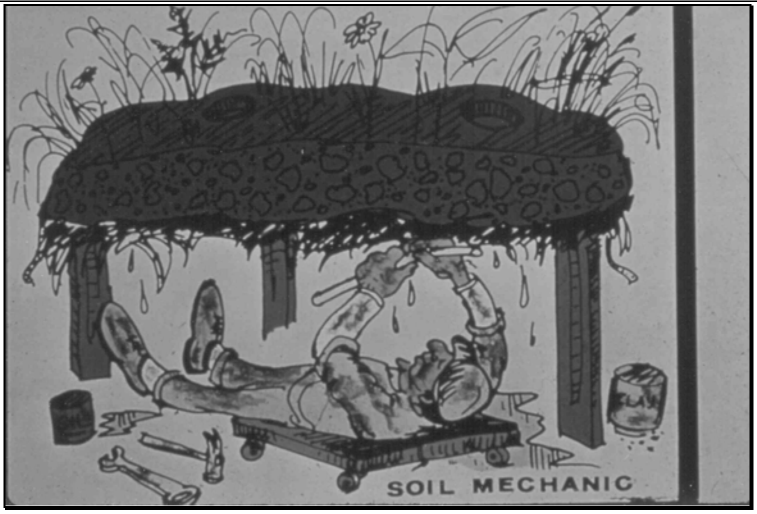

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Major Stability Problems

Circular and Sliding Block Failures

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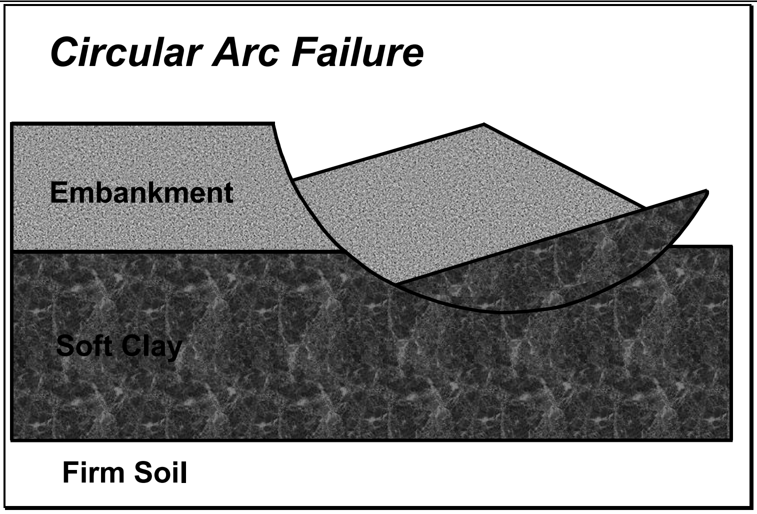

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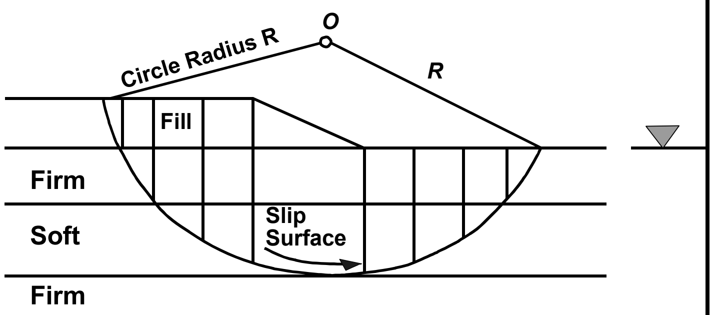
Circular Arc Stability Analysis



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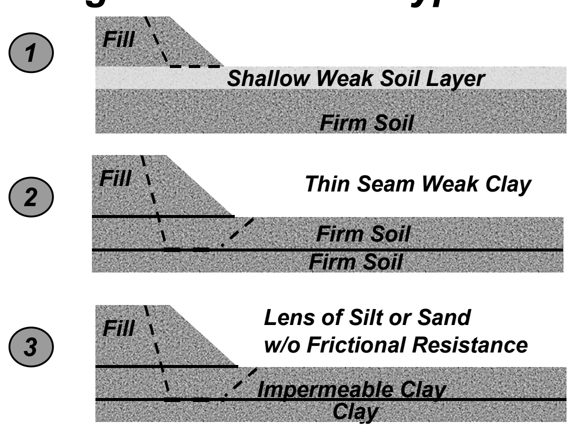
Sliding Block Failure Types



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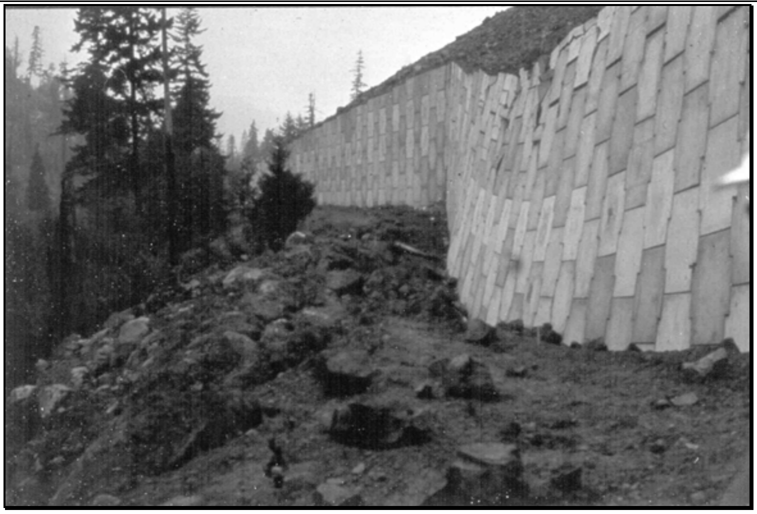

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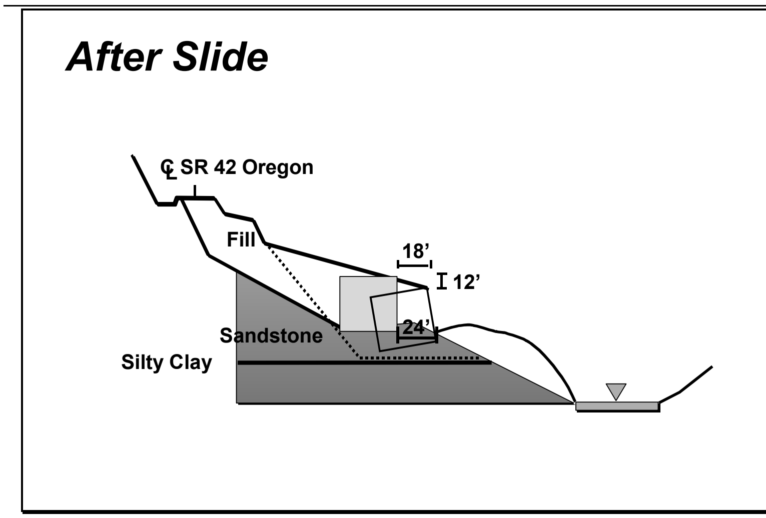

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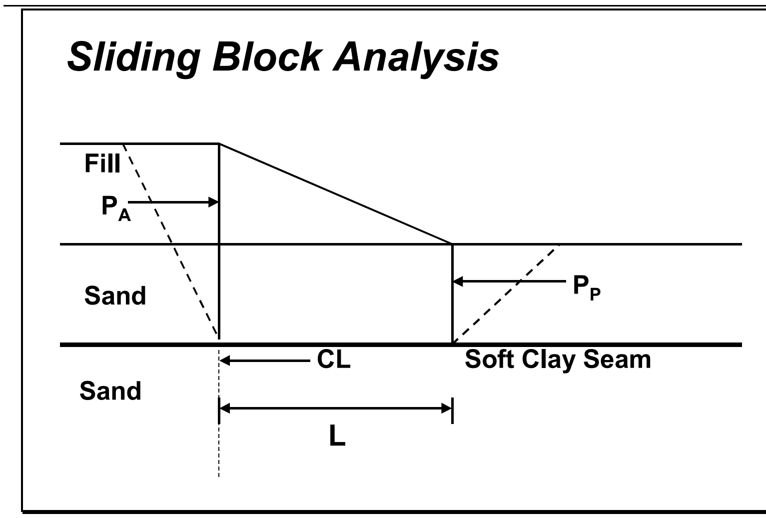
Slide 5-1-13



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Effect of Water on Slope Stability

- **Frictional Soils**
  - Below Water Table, Buoyancy Reduces Shearing Resistance
- **Clays**
  - Cohesive Strength Decreases as Moisture Content Increases

Slide 5-1-15

Effect of Water on Slope Stability (Cont'd)

- **Fills on Clays and Silts**
  - Soil Consolidates as Water is Squeezed Out - Factor of Safety Increases With Time
- **Cuts in Clay**
  - Soil Absorbs Water When Overburden Pressure Removed - Factor of Safety Decreases With Time

Slide 5-1-16

Effect of Water on Slope Stability (Cont'd)

- ***Shales, Claystones, Siltstones, Etc.***
  - ***Weak Rock Materials "Slake" When Exposed to Water - Embankments Undergo Internal Settlement or Failure***

Slide 5-1-17

Embankments: Recommended Safety Factors

$$\textit{Safety Factor} = \frac{\textit{Resisting}}{\textit{Driving}}$$

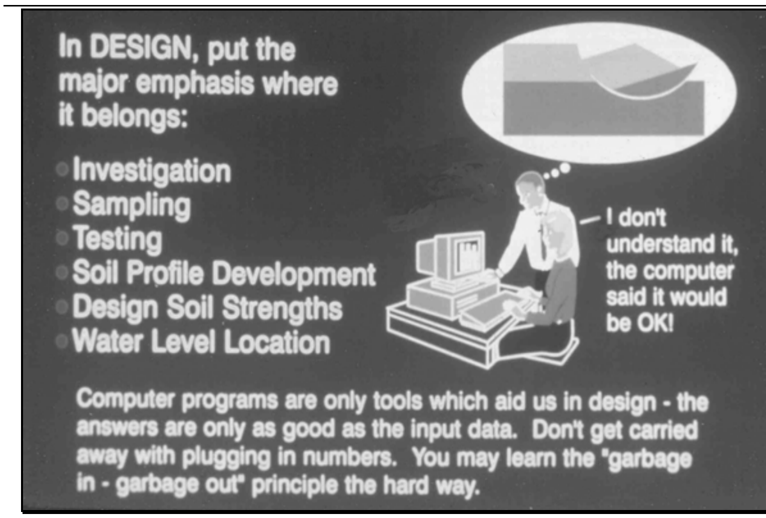
- ***End Slope Conditions***
  - ***Minimum Safety Factor = 1.30***
- ***Side Slope Conditions***
  - ***Minimum Safety Factor = 1.25***

Slide 5-1-18

Basis for Selection of Design Safety Factor

- ***Confidence in Subsurface Data (Particularly Soil Strength Value)***
- ***Stability Analysis Method***
- ***Consequences of Failure***

Slide 5-1-19



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SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Failure Analysis Methods

- ***Rule of Thumb***
- ***Hand Solutions***
- ***Computer Programs***

Slide 5-1-21

SOILS AND FOUNDATIONS WORKSHOP

$$F.S. = \frac{\Sigma\ Resisting\ \ Moments}{\Sigma\ Driving\ \ Moments}$$

$$= \frac{\Sigma\ \ N\ Tan\phi\ R + \Sigma\ \ Cl\ R}{\Sigma\ \ T\ R}$$

$$\therefore F.S. = \frac{\Sigma\ Resisting\ \ Forces}{\Sigma\ Driving\ \ Forces}$$

$$= \frac{\Sigma\ \ N\ Tan\phi + \Sigma\ \ Cl}{\Sigma\ \ T}$$

Slide 5-1-22

SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Analysis for Factor of Safety

The Rule of Thumb is:

$$\text{Factor of Safety } (F.S.) = \frac{6C}{\gamma_{Fill} \times H_{Fill}}$$

Where: C = *Cohesive Strength of Clay (psf)*

γ_{Fill} = *Fill Soil Unit Weight (pcf)*

H_{fill} = *Fill Height (ft.)*

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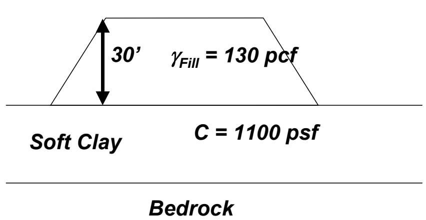
SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Analysis Rule of Thumb Example



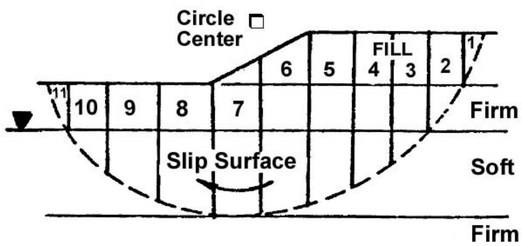
$$F.S. = \frac{(6)(1100)}{(130)(30)} = 1.69$$

Slide 5-1-24

SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Failure Normal Method of Slices - Computation by Hand

1. ***Draw Cross Section to Natural Scale***
2. ***Select Failure Surface***
3. ***Divide Mass into 10-15 Vertical Slices***



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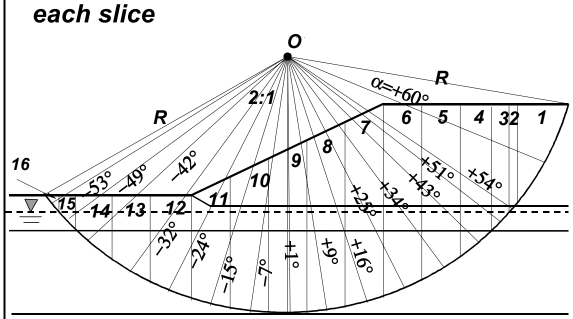
SOILS AND FOUNDATIONS WORKSHOP

Circular Arc Analysis

Extend rays from circle center "O" to the failure surface at the projected centroid of each slice



Note that slices 1 through 9 have positive α angles and contribute to the driving force. Slices 10 through 16 have negative α angles and reduce the net driving force.

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SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices - Computation by Hand

4. ***Compute Total Weight (W_T) of Each Slice***
5. ***Compute Resisting Forces: N Tanϕ - μl (Frictional) and Cl (Cohesive) for Each Slice***
6. ***Compute the Tangential Driving Force (T).***

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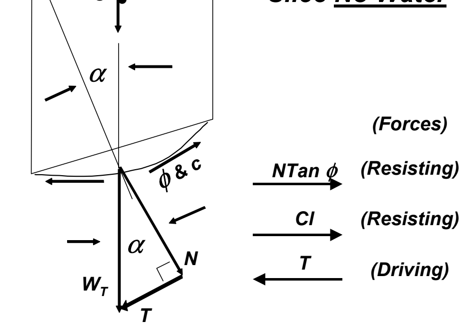
SOILS AND FOUNDATIONS WORKSHOP

Forces on One Slice No Water



C = Cohesion along slice base

Tan ϕ = Coefficient of friction along slice base

W_T = Total slice weight

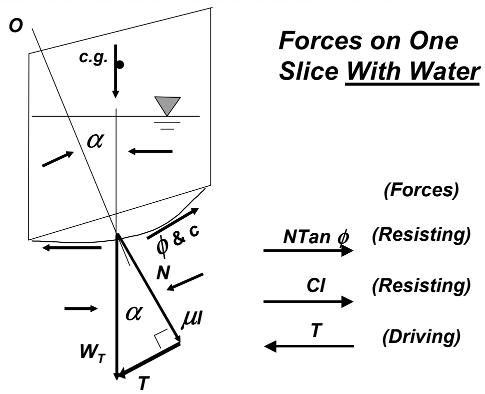
T = W_T Sin α

N = W_T Cos α

Slide 5-1-28

SOILS AND FOUNDATIONS WORKSHOP

Forces on One Slice <u>With Water</u>



μ = Water pressure on slice base

= Avg. $h_{water} \times \gamma_w$

μl = Water uplift force

W_T = Total slice weight

(use γ_{Total} both above and below W.T.)

Note $\rightarrow N = W_T \text{ Cos } \alpha - \mu l$

$T = W_T \text{ Sin } \alpha$

Slide 5-1-29

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices - Computation by Hand

7. Sum Resisting and Driving Forces for All Slices and Compute Safety Factor (F.S.)

Slide 5-1-30

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices - Example for One Slice with No Water

Assume:

- γ_{total} ***= 120 pcf, slice height = 10', slice width = 10',*** ϕ ***= 25°,*** α ***= 20°, l =11', C = 200 psf.***

- ***Find: Resisting and Driving Forces***

Slide 5-1-31

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices - Example Solution

$W_T = \gamma_{total}$ ***x slice area (x 1' thick)***

= 120 pcf x 10' x 10'

= 12000 lbs

$N = W_T \cos\alpha - \mu l$

= 12000 lbs x Cos 20°

= 11276 lbs

Slide 5-1-32

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices - Example Solution (Cont'd)

N Tan ϕ = 11276 x Tan 25°
= 5258 lbs

Cl = 200 psf x 11' x 1'
= 2200 lbs

T = W_t Sin α
= 12000 lbs x Sin 20°
= 4104 lbs

Slide 5-1-33

SOILS AND FOUNDATIONS WORKSHOP

Normal Method of Slices Group Exercise

Assuming the water is 5' above the slice base, which of the force components change in this exercise?

Slide 5-1-34

SOILS AND FOUNDATIONS WORKSHOP

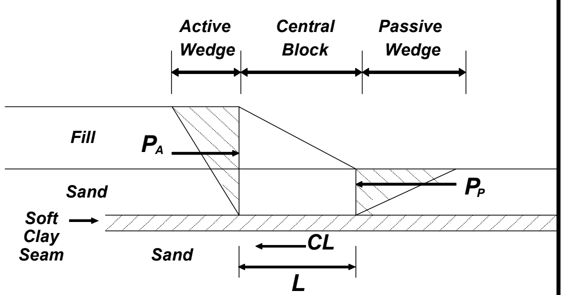
Sliding Block Failure Analysis Methods

- ***Hand Solution***
- ***Computer Solution***

Slide 5-1-35

SOILS AND FOUNDATIONS WORKSHOP

SLIDING BLOCK ANALYSIS



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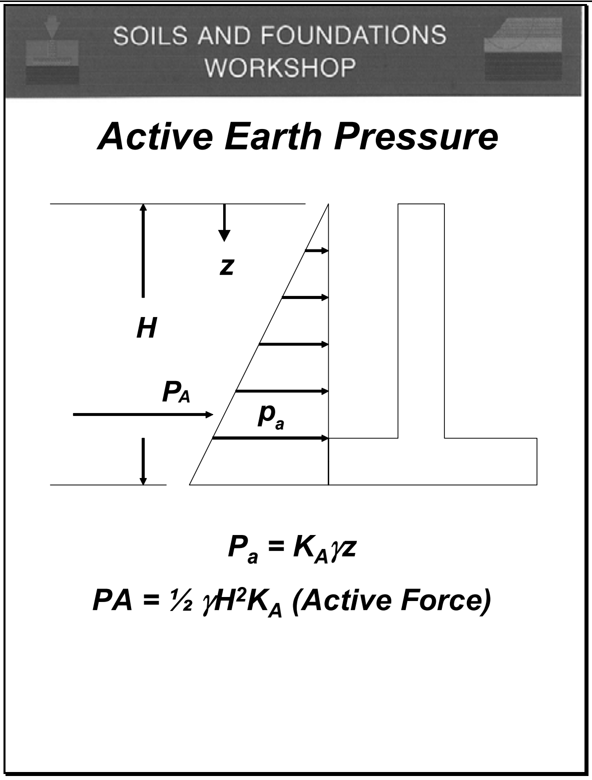

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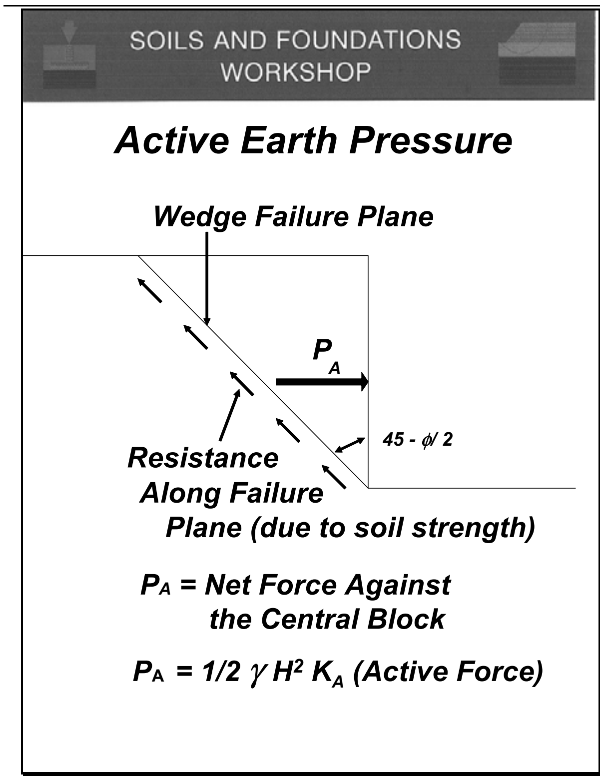

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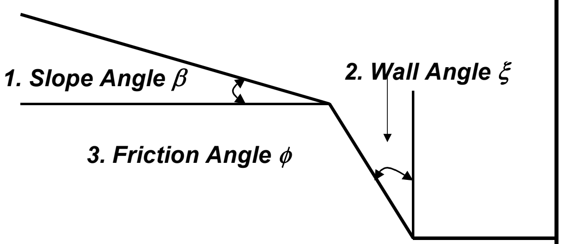
SOILS AND FOUNDATIONS WORKSHOP

Active Earth Pressure

$K_A = Tan^2(45 - \phi/2)$

(For $\beta = 0$, $\xi = 0$)

K_A varies with:



If ξ or $\beta \neq 0$, compute K_A from formulas or charts in soils textbooks

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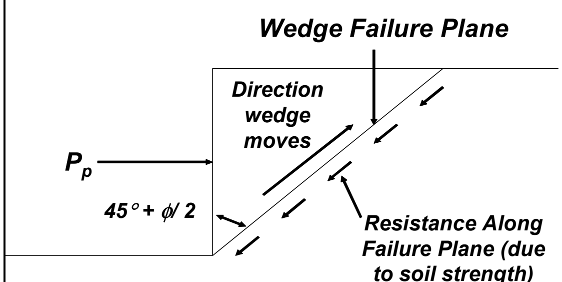
SOILS AND FOUNDATIONS WORKSHOP

Passive Earth Pressure



P_P = <u>Passive</u> Force

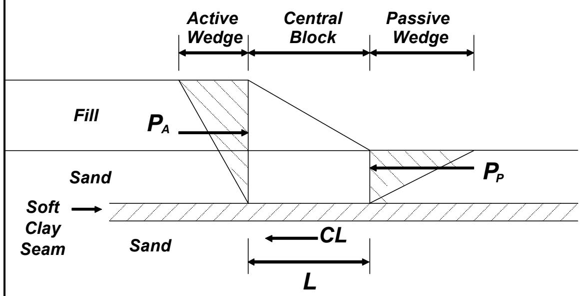
$P_P = ½ \gamma H^2 K_P$

$K_P = Tan2\ (45° + \phi / 2)$
(If $\beta = 0$, $\xi = 0$)

Slide 5-1-40

SOILS AND FOUNDATIONS WORKSHOP

SLIDING BLOCK ANALYSIS



P_A = Active Driving Force = $\frac{1}{2}\gamma H^2 K_A$

P_P = Passive Resisting Force = $\frac{1}{2}\gamma H^2 K_P$

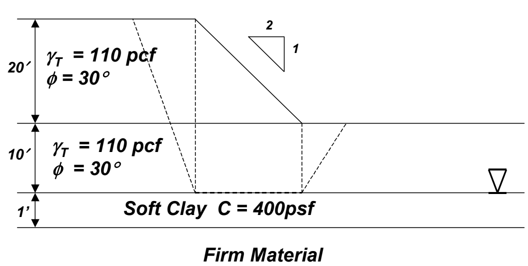
CL = Resisting Force Due To Clay Cohesion

$$F.S. = \frac{\text{Resisting Forces}}{\text{Driving Forces}} = \frac{P_P + CL}{P_A}$$

Slide 5-1-41

SOILS AND FOUNDATIONS WORKSHOP

Example 5.1: Find the Safety Factor For The 20′ High Embankment By The Simple Sliding Block Method Using Rankine Pressure Coefficients, for the Slope Shown Below.



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SOILS AND FOUNDATIONS WORKSHOP

Solution:

Step 1: Compute Driving Force (P_A)

- ***Active Driving Force (P_a) (consider a 1 ft. wide strip of the embankment)***

$$P_A = \frac{1}{2}\gamma_T\ H^2\ K_A$$

(Use γ_T as the water table is below the failure plane)

$$K_A = Tan^2(45 - \frac{\phi}{2}) = Tan^2(45 - \frac{30}{2}) = 0.33$$

$$P_A = \frac{1}{2}(0.110\ kcf)(30')^2(0.33)(1') = 16.5K$$

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SOILS AND FOUNDATIONS WORKSHOP

Solution (cont'd):

Step 2: Compute Resisting Force (Cl & P_p)

- ***Central Block Resistance (Cl)***

$$Cl = (0.400\ ksf)(40')(1') = 16.0K$$

- ***Passive Resisting Force (P_p)***

$$P_p = \frac{1}{2}\gamma_T\ H^2 K_p$$

$$K_p = Tan^2(45 + \frac{\phi}{2}) = Tan^2(45 + \frac{30}{2}) = 3.0$$

$$P_p = (\frac{1}{2})(0.110\ kcf)(10)^2(3.0)(1') = 16.5K$$

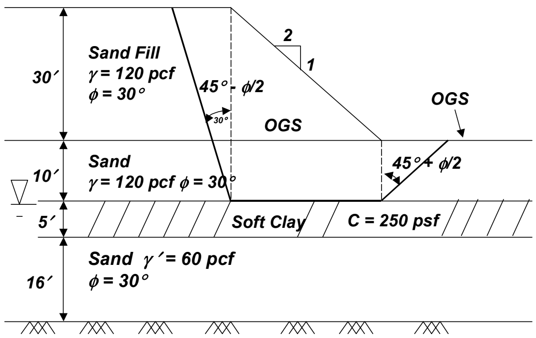
$$Safety\ \ Factor = \frac{Cl + P_p}{P_A} = \frac{16.0K + 16.5K}{16.5K} = 1.97$$

Slide 5-1-44

SOILS AND FOUNDATIONS WORKSHOP

Student Exercise NO. 2
Sliding Block Analysis

(1) Using a Rankine sliding block analysis, determine the safety factor against sliding for the embankment and assumed failure surface shown.



(2) <u>EFFECT OF RISE IN WATER TABLE:</u> Consider the changes in resisting and driving forces in Part 1 assuming that water table rises 10' to the original ground surface.

Slide 5-1-45

SOILS AND FOUNDATIONS WORKSHOP

Slope Stability

- ***Compute Resisting and Driving forces***
- ***Explain the Effects of Water Pressure on Frictional Resistance***

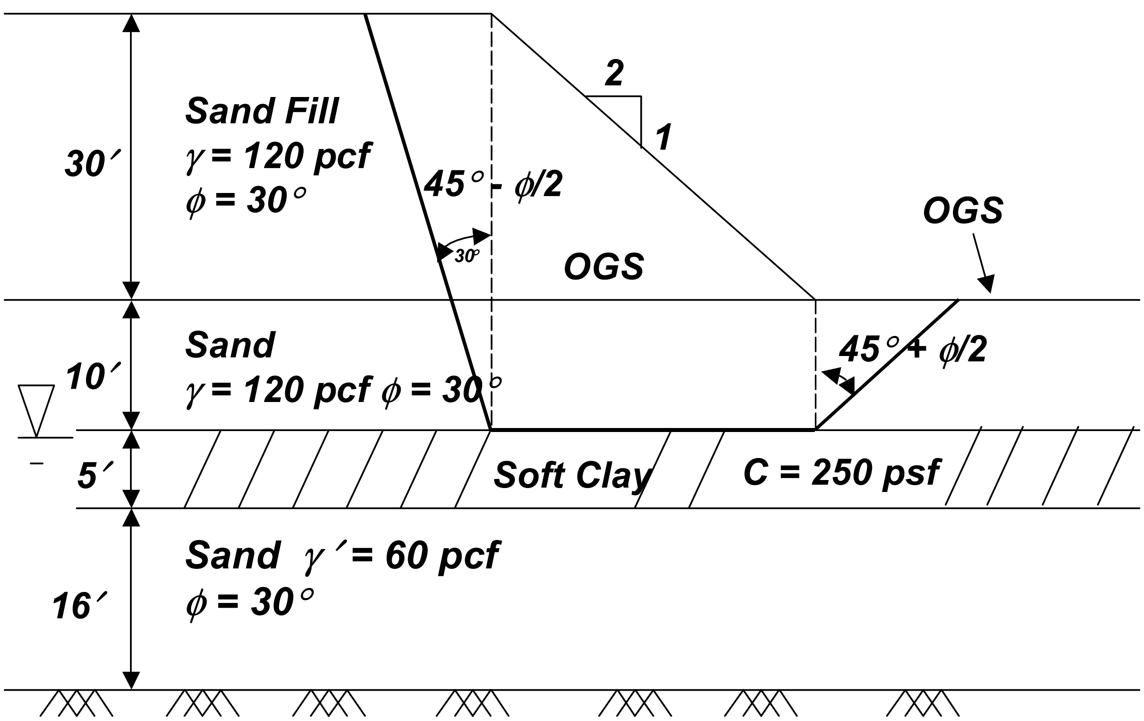
Activities: Circular Arc
Sliding Block

Slide 5-1-46

SOILS AND FOUNDATIONS WORKSHOP

Student Exercise NO. 2
Sliding Block Analysis

(1) Using a Rankine sliding block analysis, determine the safety factor against sliding for the embankment and assumed failure surface shown.



(2) <u>EFFECT OF RISE IN WATER TABLE:</u> Consider the changes in resisting and driving forces in Part 1 assuming that water table rises 10’ to the original ground surface.